CHAPTER 10

Effect of Land Application of Biosolids on Animals and Other Organisms

INTRODUCTION

Land application of biosolids can affect domestic animals and wildlife through the direct ingestion of soil, plant materials, or feed grown on biosolids-amended soil. The U.S Environmental Protection Agency (USEPA), in promulgating the 40 CFR Part 503 regulations, considered the uptake of potentially toxic chemicals or elements that can affect the animal or accumulate in body parts that may become part of the human food chain. Grazing cattle can ingest 1% to 18% of their dry matter intake as soil, and sheep may ingest as much as 30%, depending upon management and the seasonal supply of forage (Fries, 1982; Logan and Chaney, 1983; Harrison et al., 1997). Healy (1968) reported that dairy cattle consumed anywhere from 200 to 600 kg of soil per year, depending on soil and grazing conditions. This could represent approximately 2% of the diet. Chaney (1980) estimated that as much as 6% of the dry matter consumed by cattle in fescue pastures may be biosolids that adhere to the grass, even after several rainfalls. Chaney also indicated that animal grazing studies reveal direct ingestion of biosolids adhering to forage surfaces is the major source of dietary Cd. In promulgating the 40 CFR 503, USEPA evaluated the risk potential to domestic, wildlife, and other organisms from heavy metals as a result of land application of sewage sludge.

The potential impact to animals and other organisms could be the result of the following:

- Pathogens
- Trace elements, especially heavy metals
- Toxic organic compounds

The literature on this subject is rather meager. Land application of biosolids can be beneficial to animals and other organisms or could be potentially harmful, as will be discussed in this chapter.

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Table 10.1 Mean Apparent Adsorption of Some Heavy Metals by Sheep Fed a Diet Containing Sewage Sludge

Element	Composition in Diet Containing Sewage Sludge (mg/kg)	Control (mg)	Diet Containing Sewage Sludge (mg)
Cd	12.1	ND	+0.6
Cr	143	ND	+10
Cu	912	+1.0	+36
Hg	3.4	+0.073	+0.161
Pb	52	ND	–22.8
Zn	456	–28	–91.7

ND – essentially zero within the limits of detection.

Negative values indicate that more was excreted than adsorbed. No account was provided from domestic water intake.

Source: Smith et al., 1976.

ANIMALS

Domestic

In several studies, domestic animals were fed sewage sludge as part of their daily rations. These represent extreme cases and do not represent normal agricultural practices. However, the results can be useful in understanding the potential impact to animals from consuming large quantities of sludge. USEPA Pathway 10, in the risk assessment of the 40 CFR 503 regulations, offers the closest evaluation of these extreme conditions.

Smith et al. (1976) evaluated the feeding of sewage sludge as a feed supplement to sheep. The apparent absorption of several elements is shown in Table 10.1. The negative adsorption of Pb and Zn indicated that more of the element was excreted than adsorbed. Blood levels did not show appreciable increase in any elements reported. In a subsequent study, cattle were fed sewage sludge solids in supplements. The data on elemental content of kidneys are shown in Table 10.2. There was no difference between the control and the diet containing sewage sludge for Cd, Cr, Hg, Ni, and Zn. Lead was significantly higher from the sludge diet. The authors concluded that the risk to animal health or humans consuming the meat was small.

In the same study, the authors reported on using sewage sludge incorporated into pelleted supplement feed to animals on a range. The results indicated that feeding sewage sludge in a supplement did not cause a significant change in elemental content of blood and livers.

Smith et al. (1978) reported that dietary sewage sludge increased detectable levels of five of 22 pesticides measured in the adipose tissue after 68 days. Levels of Fe and Pb in livers and kidneys were increased as compared to controls, but not beyond levels reported for animals fed conventional diets. In another trial, animals pastured on the range received supplements with cottonseed and sewage sludge. Both supplements increased calf weights over unsupplemented controls.

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Table 10.2 Element Content of Kidneys of Cattle as Affected by Sewage Sludge Solids at 20% of Diet after 68 Days

Element	Composition in Diet Containing Sewage Sludge (mg/kg)	Contents of Kidney Control (mg Dry Weight)	Contents of Kidney Diet Containing Sewage Sludge (mg Dry Weight)
Cd	3.5	1.19 ± 0.47	1.49 ± 0.79
Cr	56.5	0.96 ± 0.32	0.65 ± 0.26
Cu	149	18.5 ± 0.80	16.4 ± 0.80
Hg	1.51	0.108 ± 0.075	0.130 ± 0.051
Ni	54	1.60 ± 0.54	1.77 ± 0.53
Pb	81	2.62 ± 0.14	8.43 ± 2.28
Zn	302	90.8 ± 4.5	97.3 ± 10.0

Source: Smith et al., 1978.

One of the earliest comprehensive studies (Baxter et al., 1982) was conducted by the Animal Science Department of Colorado State University in conjunction with the Metropolitan Denver Sewage Disposal District No. 1 (currently Metro Denver Water Reclamation District). This study applied biosolids to an 809-ha (2,000-acre) site from 1969 to 1975. Biosolids filter cake was applied to the surface at the rate of approximately 67 dry Mg/ha (30 dry tons/acre), and plowed under. After a 2-month fallow period, the fields were planted to forage crops, such as winter wheat, oats, sorghum, or Sudan grass.

A herd of 300 to 500 beef cattle continuously grazed the entire area and had ample opportunity to ingest biosolids contaminants. With the exception of Pb, the application of biosolids increased the heavy metal content of the forage. The studies evaluated 12 old cows from the biosolids application site and six cows from a control site where no biosolids were applied. The animals were slaughtered and samples of kidney, liver, bone, muscle, and fat tissues were analyzed for heavy metals. The data are shown in Table 10.3.

The concentration of several refractory organic compounds was also determined. These data, presented in Table 10.4, show no elevated levels of refractory organic compounds in fat tissues.

Biosolids-exposed cattle had higher concentrations of Cd and Zn in kidney and higher Pb concentrations in bone tissue than for the control cattle. These concentrations, however, were within the normal range for cattle of that age. No differences in metal concentrations of muscle tissues existed between the control and biosolids-exposed animals. Friedberg et al. (1974) indicated that Zn may be increased in the organ to counteract toxic effects of Cd.

A significant decrease in Cu content of the liver in the biosolids-exposed cattle was observed, indicating Cu deficiency. The authors found this somewhat unusual; though salt blocks contained low levels of Cu, the forage contained Cu. Mills and Delgarno (1972) indicated that Cd may be an antagonist to Cu.

There were no significant differences in lead concentration in the kidney and liver for the control and exposed animals. The study also evaluated the effect of direct feeding of biosolids as a percentage of the cattle diet.

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Table 10.3 Heavy Metal Concentrations in Several Tissues of Biosolids-Exposed Cattle and Control Cattle

Tissue and Group	Heavy Metal (µg/g Dry Weight)								
	As	Cd	Cu	Hg	Mo	Ni	Pb	Se	Zn
Kidney – control	0.03	5.9	16.3	0.12	1.7	<0.5	0.9	5.2	76
Kidney – exposed	0.02	16	16.1	0.06	1.6	<0.5	0.8	5.1	93
Liver – control	0.02	0.8	19	0.02	3.2	<0.8	0.25	1.7	113
Liver – exposed	0.02	1.4	4.6	0.02	2.7	<0.3	0.26	1.0	129
Bone – control	<0.03	0.016	0.5	<0.02	0.15	<0.7	1.5	0.06	58
Bone – exposed	<0.02	0.011	1.3	<0.02	0.35	<0.5	3.1	0.1	68
Muscle – control	<0.02	<0.01	2.9	<0.004	<0.03	<0.2	<0.2	0.67	262
Muscle – exposed	<0.02	<0.04	2.5	<0.004	<0.05	<0.4	<0.2	0.81	247

Source: Baxter et al., 1982, *J. Environ. Qual*. 11: 615–620. With permission.

Table 10.4 Concentration of Refractory Organic Compounds in Fat Tissue of Control and Biosolids-Exposed Cattle

Organic Compound	Control (µg/kg Wet Weight)	Exposed (µg/kg Wet Weight)
Hexachlorobenzene	<10	<10
Alpha-hexachlorocylohexane	10	30
p,p' –DDE	10	10
Dieldrin	10	10
PCBs (Arclor 1254)	500	500

Source: Baxter et al., 1982*, J. Environ. Qual*. 11: 615–620. With permission.

Dowdy et al. (1983) studied the performance of goats and lambs fed corn silage produced on biosolids-amended soil. Cadmium and zinc had increased as a result of biosolids application. Cadmium levels in silage reached a high of 5.26 mg/kg, following an accumulated Cd application of 25.2 kg/ha. Total dry matter intakes by goats did not differ among the control and three biosolids treatments in any of the 3 years. Table 10.5 shows the milk production and feed efficiency for female goats and the feed efficiency for lambs fed corn silage grown on biosolids-amended soils. Dairy milk production for the goats fed silage grown on biosolids-amended soils did not differ significantly between breeds, nor between the control and the average of biosolids treatment. Feeding high Cd silage continuously for 3 years did not reduce feed efficiency of dairy goats. Market lambs fed biosolids-fertilized corn silage tended to have higher daily weight gains than the control lambs.

In an earlier study, Heffron et al. 1980) reported that lambs fed corn silage grown on biosolids-amended soil had a lower rate of weight gain than lambs fed control corn silage. The rate of gain was considerably lower than those reported by Dowdy et al. (1983a).

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Table 10.5 Performance of Female Goats and Lambs Fed Corn Silage Grown on Biosolids-Amended Soils

Treatment	Goat Milk Reduction kg/day	Goat Feed Efficiency kg milk/kg feed	Lamb Feed Efficiency kg gain/kg intake
Year I			
Control	1.68	1.36	0.15
15 Mg/ha	1.42	1.36	0.18
30 Mg/ha	1.52	1.51	0.21
45 Mg/ha	1.70	1.62	0.19
Year II			
Control	1.53	0.95	0.10
15 Mg/ha	1.07	0.71	0.11
30 Mg/ha	1.42	1.02	0.10
45 Mg/ha	1.31	0.85	0.12
Year III			
Control	1.24	1.04	0.18
15 Mg/ha	0.54	0.20	0.18
30 Mg/ha	1.35	1.04	0.16
45 Mg/ha	1.27	0.91	0.18

Source: Dowdy et al., 1983a, *J. Environ. Qual*. 12(4): 473–478. With permission.

In another study, Dowdy et al. (1983b) examined the milk and blood of goats to evaluate the effect of silage produced on biosolids-amended soil. The data on milk composition of the USEPA-regulated heavy metals are shown in Table 10.6. Other elements, both macro and micronutrients, were also determined. The Cd concentration of goat milk did not increase, even though the animals received as much as 5 mg Cd each day from corn silage containing high levels of bioaccumulated Cd. Zinc concentrations of milk from control animals did not differ from milk from goats fed on silage grown on biosolids-amended soil.

Hill et al. (1998a) assessed the accumulation of potentially toxic elements by direct ingestion of soil and sewage sludge. They fed weaned lambs diets comprising dried grass and various quantities of soil and sludge. There was no limit to the diet. Voluntary intake of dry matter was greatly reduced by the inclusion of sewage sludge in the diet. There was no effect of sewage sludge on digestibility. Live weight gain was depressed. Liver and kidney weights were also reduced. The apparent availability coefficients for Cd, Pb, and Cu rose with increasing levels of sewage sludge. Concentration of these elements increased in the liver and kidney. No increases of Cd and Pb were found in muscle tissue.

In a subsequent paper (Hill et al., 1998b), the authors concluded that accumulation of potentially toxic elements can occur in both the liver and kidney of lambs given grass diets containing elevated levels of Cd derived from sludge-amended soils. The concentrations of Pb in liver and kidney never exceeded the limit for human food of 1 mg/kg fresh weight in any of the treatments. They pointed out that the research also raised some questions. Two soils were from two separate sites. The concentration of Cd in liver and kidney was lower in diets from one site than the

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Table 10.6 USEPA Regulated Heavy Metal Content of Milk Collected from Female Goats Fed Corn Silage Grown on Biosolids-Amended Soils

Treatment	Regulated Heavy Metal							
	As	Cd	Cu	Hg	Ni	Pb	Se	Zn
Year I								
Control	<0.03	<0.005	0.42	0.05	<0.15	1.05	<0.13	35.07
30 Mg/ha	<0.03	<0.005	0.32	0.06	<0.16	<1.06	<0.15	37.22
60 Mg/ha	<0.02	<0.004	0.29	0.05	<0.15	1.03	<0.11	33.81
90 Mg/ha	<0.03	<0.003	0.28	0.05	<0.014	<0.85	<0.13	30.76
Year II								
Control	<0.02	0.013	0.79	<0.02	<0.50	<0.50	<0.03	34.07
30 Mg/ha	<0.02	0.011	0.63	<0.02	<0.50	<0.50	<0.06	40.77
60 Mg/ha	—	0.009	0.58	—	<0.50	<0.50	—	34.54
90 Mg/ha	<0.02	0.009	0.53	<0.02	<0.50	<0.50	<0.05	32.85
Year III								
Control	<0.02	0.011	0.64	<0.03	<0.12	<0.33	0.22	39.45
30 Mg/ha	<0.02	0.017	0.43	<0.05	<0.13	<0.35	0.22	40.12
60 Mg/ha	<0.02	0.012	0.26	<0.06	<0.12	<0.31	0.20	34.60
90 Mg/ha	<0.02	0.009	0.29	<0.06	<0.12	<0.33	0.22	36.94

Source: Dowdy et al., 1983b, *J. Environ. Qual*. 12(4): 1983. With permission.

other site at similar levels of total intake of Cd. They concluded that more research is needed on the interaction between chemical speciation of Cd in the soil and availability to the animal.

Again, this is an extreme situation and does not represent what would happen if biosolids were land applied and incorporated into the soil to a depth of 30-cm (6 in.), which is the plow depth. Grazing animals would not consume a diet similar to the feeding experiment. Furthermore, the authors indicated that the sheep did not relish the sludge-treated soil diet. Because biosolids are not applied uniformly in fields, it can be expected that the grazing animals would shy away from heavily biosolid-laden forage.

Very few reports exist on pathogen contamination of domestic animals resulting from sludge or biosolids application. Forbes et al. (1980) reported five outbreaks of cysticerciasis from 1976 to 1979 in cattle from Scotland that were traced to the application of sewage sludge. Some 0.5% of cattle in Scotland are affected. The type applied was liquid undigested sludge.

Wildlife

Numerous studies have been conducted on wildlife coming in contact with soil or crops grown on sludge or biosolids-amended land (Hinsley et al., 1976; Williams

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et al., 1978; Anderson et al., 1982; Dressler et al., 1986; Hegstrom and West, 1989). Particular concern centers on Cd, because it can accumulate in tissues of herbivorous and omnivorous rodents inhabiting biosolids-amended land. Early studies by West et al. (1981) and Anderson et al. (1982) indicated that the concentrations were not high enough to cause toxicity to wildlife. Beyer (2000) reported that toxicity to wildlife has been exaggerated since threshold data do not support the low levels assumed.

Hinsley et al. (1976) found that, although Zn, Cd, and Ni accumulated in corn as a result of sludge application, only Cd significantly increased in the duodenal, liver, and kidney tissue of ring-necked pheasants fed corn grain from sewage-sludge amended soil. Williams et al. (1978) fed meadow voles crops grown on sludge-amended soil and found significant accumulation of Cd in kidneys and liver, but not muscle. Both of these studies did not simulate normal wildlife conditions. In a field study, in contrast, Alberici et al. (1989) did not find concentrations of Cu, Zn, Co, Cd, and Ni in vole tissues were different from those of the control group. This could be due to differential accumulation of heavy metals by plants, as well as the fact that the animals were not restricted to a specific food source, as was the case for laboratory studies.

Dressler et al. (1986) studied cottontail rabbits on mine land treated with sewage sludge. Liver and muscle tissue of rabbits collected on treated mine sites contained higher levels of Cd than laboratory controls, but overall, cottontail rabbits did not accumulate heavy metals on the sludge-amended site to a level that would be detrimental.

Hegstrom and West (1989) reported the accumulation of heavy metals in small mammals following biosolids application to forest land. Levels of Cd, Pb, Zn, and Cu were measured in the livers and kidneys of insectivorous Trobridge's shrews (*Sorex trobridgii*), shrew-moles (*Neurotrichus gibbsii*), and granivorous deer mice (*Peromyscus maniculatus*) from sludge treated and untreated sites. Heavy metal levels were higher in the livers and kidneys of Trobridge's shrews on the sludge-treated areas than from animals on the untreated sites. Only Cd was elevated in the livers and kidneys of the deer mice. Shrew-moles from the sludge sites had higher levels of Cd and Pb, but not Cu or Zn, compared with animals from the untreated sites.

The effect of Cd concentrations in omnivorous mice (*Peromyscus* sp.) and insectivorous shrews (*Sorex* sp.) inhabiting biosolids-application sites 4, 11 and 15 years after biosolids application was studied by Nickelson and West (1996). They found that kidney Cd was significantly greater in shrews than in mice on all treated sites. Although Cd levels in mice from some treated sites were significantly increased over corresponding controls, levels from the highest application site were comparable to controls found at other sites. They concluded that biosolids would not have a significant long-term effect on omnivores. Cadmium levels in shrews from all treatments, except the low-application rates, were significantly greater than controls. The authors indicated that the levels of Cd did not appear to be biologically significant.

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MICROBES

Heavy metals can affect microorganisms (McGrath et al., 1988; Giller et al., 1998). As with many organisms, heavy metals at high concentrations can be toxic. Early evidence shows that near smelters, soil microorganisms and soil microbial populations were impacted by elevated metal concentrations (Freedman and Hutchinson, 1980). Giller et al. (1998) pointed out that early research on biosolids/sewage sludge was focused on protecting against negative effects on crops, on animals grazing on land and on human exposure through the food chain. Some 20 years later, consideration was given to the effect of heavy metals in sewage sludge on microorganisms.

Reddy et al. (1983) studied the survival of *Bradyrhizobium* in sludge-amended soil and found a decline in bacterial populations. They concluded that this decline was the result of heavy metal toxicity. Madariage and Angel (1992) attributed a rapid decline in the population of *Bradyrhizobium* as to toxic concentrations of soluble salts in sludge-amended soil.

Scientists extensively studied the effect of sewage sludge on nitrogen-fixing bacteria. Several early studies were conducted at the Woburn Experiment Station at the Rothamsted Experimental Station in England (McGrath et al., 1988; Giller et al., 1998). They reported a 40% yield reduction in white clover (*Trifolium repens*), compared to field plots receiving farmyard manure, even though the application of organic matter ceased 20 years prior to the study. These authors reported that, in soils receiving sewage sludge over a period of 30 to 50 years, only ineffective *Rhizobium leguminosarium* bv. *trifoli* survived. They concluded that sludge-borne heavy metals, primarily Cd, Zn and Cu, caused these reductions.

Obbard et al. (1993) evaluated the effect of undigested sewage sludge and digested biosolids application on the presence and number of cells of *R. leguminosarium* bv. *trifolii* capable of nodulating white clover. *Rhizobium* were present in all the treatments except low pH soil with the most metal contamination. They concluded that the important factors affecting rhizobial population were soil pH, sludge type, sludge rates, and presence of heavy metals. This data differed from that reported by McGrath (1987). Others (Kinkle et al., 1987) observed an increase in the number of bradyrhizobia in soil, which rose with higher rates of sludge application.

Because of the conflicting data on the effects of heavy metals and the importance of legumes in maintaining soil fertility, Ibekwe et al. (1995) conducted a study to evaluate sewage sludge and heavy metals on nodulation and nitrogen fixation of legumes. Three legumes were studied: alfalfa (*Medicago sativa* L.), white clover (*Trifolium repens* L.) and red clover (*Trifolium pratence* L.). Soil pH and sludge type significantly affected uptake of metals, with phytoxicity observed in low pH sludge-amended soil. Nodulation was reduced but not always completely eliminated in all low pH treatments including controls (soils not receiving sludge). In soils where pH was above 6.0, there was a significant increase in shoot weight and total shoot N with addition of sludge. When pH was maintained at 6.0 or higher, results showed that heavy metals in soil, and resulting increased concentrations in the plant, did not affect nodulation and nitrogen fixation.

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The addition of biosolids increases the soil's organic matter and should enhance the soil's microbial population unless sufficient levels of toxins are present that could depress microbial activity. Sastre et al. (1996) found that applications of biosolids at recommended rates increased soil microbial activity. Banerjee et al. (1997) studied the effect of sewage sludge application on biological and biochemical soil properties. Sludge application significantly increased the microbial biomass present in the soils. Sludge application enhanced the N mineralization potential of the soil. Three soil enzymes were monitored and their activities were somewhat enhanced. There was a reduction in microbial diversity. Artiola (1997) reported that denitrification rates in semiarid soils amended with anaerobically digested biosolids were higher within and below the root zone, where biosolids were applied, compared with fertilized soils.

EARTHWORMS

Earthworms are an important component of the natural food chain. They are eaten by birds, snakes, toads, frogs, moles, and centipedes, and these animals in turn are consumed by other animals. The accumulation of heavy metals by earthworms can be toxic to organisms that consume them. Earthworms are also considered a source of protein by some humans. Ireland (1975b) indicated that the metabolic activity of earthworms can increase the solubility of Ca, Pb, and Zn in soils contaminated by heavy metals, and their activity may be important in heavy metal availability to plants.

Earthworms are bioaccumulators of certain heavy metals. Dr. Mike Ireland, a professor of animal physiology at the University College of Wales in Aberystwyth, studied the effect of Pb and Zn in the acid-soil tolerant species *Dendrobaena rubida*. The soil contained over 1000 ppm of Pb and Zn and the concentration of Pb in the earthworm exceeded over 4160 ppm (Ireland, 1975a). In another study conducted later that year, Ireland (1975b) also showed that in soil with 1713 mg/kg Pb the earthworm (*Dendrobaena rubida*) had higher levels of Pb than those in soil with 127 mg/kg Pb.

Helmke et al. (1979) reported that Hg and Cr in the casts of earthworms (*Aporrectodea tuberculata*) rose with increasing biosolids application. However, the constant concentration of these elements in earthworms indicated that these elements are not bioavailable. They also found the earthworms efficiently accumulated Cd. The concentrations of Cd, Cu, and Zn in earthworms rose while the concentration of Se fell with increasing biosolids application. Andersen (1979) also found that Cd increased with sludge application, but there was no clear inverse correlation of sludge application on Cd. In some species, he found that sludge application lowered Cd concentration.

Hartenstein et al. (1980) found that the conversion of waste-activated sludge into egesta by the earthworm *Eisenia foetida* resulted in neither an increase nor decrease of acid-extracted Cd, Ni, Pb, or Zn. The addition of 2500 ppm of copper or copper sulfate to activated sludge killed the earthworms within a week. In a subsequent paper, Hartenstein et al. (1981) concluded that except under extreme conditions, the

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level of heavy metals in activated sludges will not have an adverse effect on the growth of *E. foetida*.

Beyer et al. (1982) found that earthworms from four sites amended with sludge contained significantly more Cd (12 times), Cu (2.4 times), Zn (2.0 times) and Pb (1.2 times) than did earthworms from control sites. In general, Cd and Zn were concentrated by earthworms relative to soils, and Cu and Pb were not concentrated.

Pietz et al. (1984) determined the concentration of heavy metals in two earthworm species on a biosolids-amended strip mine reclamation site. Although two species, *Lumbricus terrestris* and *Aporrectodea tuberculata* were found on biosolids-amended nonmined fields, only *A. tuberculata* was found in the biosolids-amended and nonamended minesoil fields. Earthworm metal concentrations generally increased over time in all the fields. Metal concentrations in the earthworm accumulated in this order: Cu > Cd > Ni > Cr > Pb > Zn. Earthworm concentrations of Cu and Cd were significantly related to the amounts found in biosolids. This was not true of Ni, Cr and Pb. They concluded that the higher Cd and Cu concentrations in earthworms from biosolids-amended fields might pose a potential hazard to predators.

In Chapter 2 it was shown that the concentration of heavy metals in biosolids has decreased considerably since the 1980s. The lower levels in biosolids today would reduce the concentration of heavy metals in earthworms and lower the potential risk to their predators.

CONCLUSION

The potential toxic effect of land-applied biosolids to both domestic animals and wildlife appears to be very low. Heavy metal concentrations in biosolids during the past 15 years have decreased considerably. Feeding experiments of biosolids-amended soil to animals does not represent the potential intake of heavy metals by grazing animals. The distribution of biosolids on fields is not uniform and today's practices incorporate the biosolids to a depth of 30 cm or more. These practices greatly reduce the potential exposure of grazing animals to potentially toxic elements.

With respect to the effects on the microbial population, the data are very diverse and inconclusive. Some studies showed negative effects and others showed no effects. The studies with earthworms revealed that they are bioaccumulators of heavy metals. Early studies indicated that for some metals the accumulation could represent a risk to predators. As biosolids metal levels decrease, the potential accumulation in the earthworm should decrease, as should the danger to predators.

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